SECURITY CLASSIFICATION OF THIS PAGE

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(2)

REPORT DOCUMENTATION PAGE

DTIC ELECTE JUN 1 1987 D

AD-A181 218

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release
Distribution Unlimited

5. MONITORING ORGANIZATION REPORT NUMBER(S)
AFOSR-TR- 87-0749

6a. NAME OF PERFORMING ORGANIZATION
BDM CORP

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION
AFOSR

6c. ADDRESS (City, State and ZIP Code)
7915 Jones Branch Drive
McLean, Va 22102-3396

7b. ADDRESS (City, State and ZIP Code)
Bldg 410
Bolling AFB, DC 20332-6448

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
AFOSR

8b. OFFICE SYMBOL (If applicable)
NE

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
F49620-86-C-0030

8c. ADDRESS (City, State and ZIP Code)
Bldg 410
Bolling AFB, DC 20332-6448

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
61102F	4952	02 DARPA	

11. TITLE (Include Security Classification)
Application of Optical computing to problems with Symbolic Computations

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT
Quarterly R&D

13b. TIME COVERED
FROM 15/01/86 TO 31/01/87

14. DATE OF REPORT (Yr., Mo., Day)
87 May 14

15. PAGE COUNT
6

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Research efforts ~~during the preceding quarters~~ identified some critical operations of symbolic computing. Of these operation, two primitives--central to the difference between symbolic and numeric computation--appeared ideally suited for optical implementation because of their parallel structure and local simplicity. These primitive operations are compare-and-exchange found in relational databases and pattern matching in inferencing systems. In this quarter, we proposed optical implementations of the compare-and-exchange operation for relational database applications.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

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22c. OFFICE SYMBOL
NE

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

SECURITY CLASSIFICATION OF THIS PAGE

THE BDM CORPORATION

AFOSR-TR- 87-0749

APPLICATIONS OF OPTICAL COMPUTING TO PROBLEMS WITH SYMBOLIC COMPUTATIONS

FOURTH QUARTERLY R & D STATUS REPORT

January 31, 1987

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Sponsored by
Defense Advanced Research Projects Agency (DoD);
ARPA Order No. 4952
Monitored by AFOSR Under Contract #F49620-86-C-0030

ARPA ORDER: 4952	CONTRACT No.: F49620-86-C-0030
PROGRAM CODE: 5D10	PRINCIPAL INVESTIGATOR: Dr. Brian G. Kushner
CONTRACTOR: The BDM Corp.	PROGRAM MANAGER: Dr. Brian G. Kushner (703) 848-7903
EFFECTIVE DATE OF CONTRACT:	JANUARY 15, 1986
CONTRACT EXPIRATION DATE:	SEPTEMBER 14, 1987
AMOUNT OF CONTRACT DOLLARS:	$ 323,303

87 6 10 18

1. **Description of progress during the reporting period, supported by reasons for any change in approach reported previously.**

Research efforts during the preceding quarters identified some critical operations of symbolic computing. Of these operations, two primitives--central to the difference between symbolic and numeric computation--appeared ideally suited for optical implementation because of their parallel structure and local simplicity. These primitive operations are compare-and-exchange found in relational databases and pattern matching in inferencing systems. In this quarter, we proposed optical implementations of the compare-and-exchange operation for relational database applications.

The most common relational database operations include special-purpose operations like selection, projection, division and join along with the logical set operations of intersection, union, difference and Cartesian product. In general, any fast sorting algorithm serves as a basis to form the logical set and most of the special-purpose operations. All procedures that sort in sublinear time--less than O(N)--require global communication between SIMD parallel processing nodes--properties inherent to many optical computing architectures. Parallel sorting algorithms--at least those representable to first order as fixed, multistage networks of processing elements--are ideal for implementation on optical architectures because they require sparse, space-variant interconnects with low fan-in/out. Moreover, the simple processing elements can be built using high-speed optical devices to further enhance the performance of network architectures.

All the relational-algebra operations described previously manipulate data structures instead of data. In general, the ultimate disposition of each datum in the structure depends on its relative value and position with respect to the rest of the data. Self-routing multistage networks are a class of parallel divide-and-conquer algorithms, where the final position of each datum is calculated

using parallel local position computations within each stage along with sparse, global interconnects between stages. The local computation, compare-and-exchange, is a generic local-position calculation and routing algorithm for multistage networks that can be modified to perform most relational-algebra operations.

Compare-and-exchange can be implemented with a variety of optical technology including analog optics, and digital optics with all-optical, hybrid optoelectronic and polarization logic. Because sorting is a multistage process, signal-to-noise-ratio considerations limit the applicability of analog implementations. However, digital approaches based on a direct mapping strategy are more flexible. Special-purpose, latching logic gates reduce the complexity of the direct mapping implementation in digital optics. In particular, bistable Fabry-Perot etalons are ideal candidates to implement latching AND gates for the compare operation because of their high speed. Because of this speed, comparison units based on bistable Fabry-Perot etalons are well suited for high time-bandwidth product signals.

Spatial-position-encoded exchange units built with all-optical logic regenerate signal levels. Thus, only signal to noise, crosstalk, uniformity and other systems engineering considerations limit the number of channels per stage and the total number of stages, and hence, all-optical exchange applies to deep networks with many high-speed inputs. In addition, the high speed of the devices indicates that the module latency will be governed by intra-module interconnect times. Furthermore, the inter-stage, space-variant connection time determines the overall sorting system latency, but the computation can be pipelined for high throughput at the expense of increased spatial and control complexity. Somewhat slower active devices, like the SEED, can be used for exchange, but they may increase the system latency and reduce the throughput. In any case, the information on each channel following a latching operation may have a higher time-bandwidth than the comparison logic to increase throughput, but the bit rate must be slower than the exchange logic.

The potential throughput is greatly increased if the exchange module uses passive switches that allow trailing information to propagate at optical media time-bandwidths. Polarization encoded switching using Wolloston prisms and controllable half-wave plates is one technology that performs passive routing. The advantage of polarization switching, in addition to its passive nature, is that exchange occurs in one stage and the data may occupy the same spatial channel. However, the frame rate of optically controlled, dynamic half-wave device arrays is presently constrained to the millisecond regime by the combined optical and electrical switching power dissipation limitations. For all these reasons, polarization coded exchange applies to small networks with long, ultra-high time-bandwidth product packets or large networks with slower signals.

There are other comparison technologies compatible with polarization exchange besides all-optical logic. In particular, electro-optic latching logic is well suited for the comparison operation. Because of the frame rate limitations of electrooptic device arrays, the bandwidth of the message headers is limited. Hybrid optoelectronic systems are possible where optics performs communication functions and electronic circuits compute the C&E operation. The hybrid technology is potentially powerful, but still in its infancy: Therefore, it is difficult to predict the relevent domains of applicability.

In conclusion, the compare and exchange operation can be implemented with a variety of optical technology. Which technology one chooses depends on the requirements of the application of interest. Unfortunately, we don't have reliable figures yet for relational-algebra operation requirements in terms of input and output formats, relation size, speed, power, throughput, etc., to determine if any of the technologies will be competitive with electronics. However, the all-optical, polarization, electrooptic and hybrid approaches to C&E appear viable at this early stage. In addition,

multistage networks of C&E modules may be useful for related problems with different performance requirements: For example, telecommunication and interprocessor message routing.

2. **Description of any major items of experimental or special equipment purchased or constructed during the reporting period.**

No such items were purchased or constructed during the reporting period.

3. **Notification of any change in key personnel associated with the contract during the reporting period.**

No changes in key personnel were made during the reporting period.

4. **Summary of substantive information derived from noteworthy trips, meetings, visits, and scientific papers during the reporting period.**

At the January meeting of the Society of Photo-optical Instrumentation Engineers in Los Angeles, BDM presented a paper entitled "Optical Implementation of the Compare-and-exchange Operation for Applications in Symbolic Computing." The presentation received a positive response from co-workers in the area of optics and symbolic computing. The work was also presented at the DARPA/AFOSR optical computing annual review in Leesburg.

5. **Summary of any problems or areas of concern on which Government assistance or guidance is desired.**

No such problems or areas exist.

6. **Statement relative to any anticipated deviation in the contractor's planned effort to achieve the objectives of the contract.**

No deviations are anticipated.

7. **Fiscal status.**

(a)	Amount currently provided for the contract:	$ 323,303
	First Increment:	249,975
(b)	Expenditures and commitments to date (1/25/87):	230,656
(c)	Estimated funds required to complete the work:	92,647
(d)	Estimated date of completion of work:	9/23/87